

Does the fireball found in AuAu collisions at RHIC resemble plasma?

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Abstract

General properties of the hot and dense hadron matter (fireball) discovered in AuAu collisions with $\sqrt{s_{NN}} = 130$ and 200 GeV at RHIC are compared with these for ideal electromagnetic plasma. None of them was found to be in contrary to those of the plasma typical signs distinguishing its from other aggregate states of the matter. The author notes that modern experimental data about the fireball properties are limited to make their comprehensive comparison with plasma signatures. The author also points out the directions needed to be studied to answer question whether the hadron matter observed in the RHIC experiments is a color analogue of the electromagnetic plasma or not.

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I. INTRODUCTION

The search for quark-gluon plasma (QGP) has been carried out for about almost three decades. The main features of this hypothetic state of the hadron matter according to [1]-[10] are as follows:

- deconfinement of quarks;
- quarks and gluons are deconfined in the volume scale of two nuclei collision but not in a single nucleon bag;
- characteristic density of energy in the collision volume is at the order of several GeV/fm³ [32]

There is no experimental confirmation to any of the above except the latter. The same is true concerning the list of features obtained by the LQCD, quark and other microscopic models which to define QGP [1],[2][3][4][5][6],[7],[8],[9]. The discussion of these features is given below.

The author of this work has considered the general properties of the hot and dense hadron matter (fireball) found in AuAu collisions with $\sqrt{S_{NN}} = 130$ and 200 GeV at RHIC to figure out how they correspond to the characteristic properties of the ideal electromagnetic plasma (further on “plasma”). The results of the performed analysis have shown that some properties of the fireball (see Table I) resemble the properties of the plasma. The other properties do not contradict this conclusion but need further clarification. Thus, the existing experimental information on the fireball produced at RHIC is not enough at present to carry out its total completed comparison with the plasma. The work has shown that to reach completeness in future comparisons, it is necessary to have the following:

- a) more precise experimental data to study the screening effects of the color charges in the fireball medium;
- b) direct experimental confirmation of quasi-particle excitations in the fireball medium;
- c) direct experimental estimations of the fireball temperature, for example, by measuring the thermal photon spectrum in the hot phase of the fireball development.

The experiments mentioned above can give a concluding answer to the question: Is the hadron matter observed at RHIC a color analogue of the plasma?

II. MAIN PROPERTIES OF THE ELECTROMAGNETIC PLASMA. THEIR COMPARISON WITH FEATURES OF THE HADRON MATTER PRODUCED IN HEAVY NUCLEI COLLISIONS AT RHIC AND SPS CERN.

Let us review the main properties of the electromagnetic plasma. According to [11],[12] plasma is a state of substance having a set of the following features:

1. Quasineutrality (or neutrality) on the electric charge of the system in general;
2. Presence of separated charges (the charge dissociation of the atom);
3. Collective character of particle interactions of the system;
4. The presence of the wave motions in the system beside its chaoticity (quasi-particle degrees of freedom);
5. Charge screening in the plasma medium.

Besides, the plasma (not in the outside field) is characterized by the following microscopic scales reflecting its properties mentioned above and some others: ionization energy of the plasma atoms, Langmuir oscillation frequency and the radius of Debay charge screening - r_D .

All varieties of plasma in classical physics are known to have these features in one or another extent. These properties can be also considered as plasma macroscopic signatures to identify the states of the matter. Does the hadron matter produced in heavy nuclei collisions at ultra relativistic RHIC energies, possess similar properties? The question has not been discussed in the literature in this configuration yet. To get an answer, let us consider some experimental facts and conclusions from their analysis obtained earlier. Our consideration will be qualitative. While comparing we suppose that the analogue of the plasma electric charge in the hadron matter is, naturally, a color charge.

Since the nucleon is colorless and there are no free quarks in the nature [14] (no free color charges then), condition 1 will be also preserved in the case of the hadron matter, this time as its “color neutrality”. So, property 2 will reflect separation of the color charges in the fireball, i.e. deconfinement of quarks in the fireball medium.

The character of the third plasma property - collective interactions of its particles, is determined by the Coulomb forces between the charges in the plasma which reduce slower

with the distance than Van der Waals forces acting between neutral atoms. It is not evident that similar to the electron plasma field there will be the collective forces field established between the fireball constituents. But it turns out that exactly this collective interaction takes place between the light quarks in the initial hot phase of the fireball evolution at RHIC energies. This was shown by the hydrodynamic analysis [15] of the elliptic flows of light mesons and baryons in AuAu collisions with $\sqrt{S_{NN}} = 200$ GeV. Recently an analogous type of interactions has been found to exist also between the heavy and light quarks in the fireball matter at RHIC. This conclusion goes from the analysis of the energy spectra and values of the elliptic flows of fast electrons of the heavy mesons produced from $b-$, $c-$ and other quarks [16],[17]. Thus the collective fireball properties are substantiated by serious experimental data.

The other plasma property is related with charge density fluctuations of the plasma in the time. They reveal themselves as the quasi-particles motion in the plasma matter [13]. In the case of the fireball the appearance of this motion form significantly depends on the color dielectric properties of the fireball medium. The medium effects open one more area to compare the behavior of these two forms of the matter. So, it has been figured out that to take the oscillation degrees of freedom into account (for example, in the form of gluon plasmons [18] in the quark-gluon medium) is important while calculating the radiation losses of the parton mini-jet energy when they are moving through this medium.

First indications on this effect to exist in the fireball medium produced in the central collisions at RHIC, were obtained in the work [19]. For the first time it allowed one to solve successfully the known problem of strong suppression of the π^0 meson yields in AuAu collisions at 130 GeV. The author has used the so called quasi-particle model of QGP where the quark-particle excitations and gluons with transverse polarization are described as massive quasi-particles with parameters depending on the medium properties [20]. The model is characterized by big energy losses of the gluon and quark jets in the QGP medium. This peculiarity gives an opportunity to hope that it will promote a solution of another analogous puzzle - suppression of the charmed and other heavier meson states produced in the collisions at RHIC [21],[16]. There is no satisfying explanation of this problem. All the suppression mechanisms offered earlier (also including the plasmon degrees of freedom in the gluon component of QGP) enable us to obtain only the qualitative agreement of the experimental data [22]. In principle, it can be improved if to take two-particle resonances [23]

or three-particle heavy quark collisions in the medium [17]. But so far the both mechanisms remain only as indications of the opportunity to excite the simplest quasi-particle states in the quark-gluon fireball medium. It is needed to study further this important problem to understand whether the heated fireball medium (at RHIC) has quasi-particle degrees of freedom.

To obtain direct but not subordinate experimental signals on the existence of these degrees of freedom, would be extremely important in studying the fireball properties. One of these experiments of this type should carry out collisions of partially ionized atoms of heavy nuclei at RHIC and LHC. In this case the electrons of the atom shells of ions will be like an electromagnetic probe to be used, in principle, for direct study of the quasiparticle excitations of the produced fireball medium.

Finally about property 5. The ability of screening the charges leads to the appearance of the characteristic scale r_D in the plasma medium which describes the plasma field at distances $r < r_D$. As it is seen from the LQGP calculations [24], the analogous scale appears also in the color-charged matter. In the consequence of the above one can expect significant suppression of the production of some atom-similar systems which are rather prolonged, for example, χ and ψ' charmonium states. These effects are traditionally called “melting” states. The first experiments to observe these melting J/ψ , ψ' , χ charmonium states on the SPS beams at CERN ($\sqrt{S_{NN}} = 17$ GeV) [21] and later at RHIC ($\sqrt{S_{NN}} = 130$ GeV) [25],[26] have confirmed the general character of the expectations. But a theoretical interpretation of the experimental data still remains to be not clear: not all principally important peculiarities of the yield of J/ψ , ψ' , χ meson states have been observed so far [27]. The measurement precision needs to be improved. The study of the problem is going on.

In conclusion we have to emphasize that a specific feature of the substance state in the form of plasma is the collective character of its constituents interaction and excitations of its medium. Now none of the experimentally known properties of the fireball produced in the collisions of heavy nuclei at $\sqrt{S_{NN}} = 130$ and 200 GeV, contradicts this plasma property. On the contrary, the experimental data have shown that some part of them reveals undoubtedly properties similar to 1, 3 and, probably, 4. In other cases (properties 4 and 5) this similarity in the properties does not contradict to the experiment [17],[19],[21],[25],[27] but it does not result from them with enough argumentation either. So that is why it needs to be reliably confirmed either. The summary of the properties of the plasma and fireball produced in the

collisions of heavy nuclei at collider RHIC and SPS, is shown in Table I.

III. COMPARISON OF QGP AND ELECTRON PLASMA SIGNATURES

For many years the QGP features obtained on QCD calculations [1]-[10] (see Table II.) were the only characteristics to identify QGP in the experiments at RHIC and SPS. It is a natural wish to clarify how these properties agree with the plasma signatures 1-5. The results of comparison are given below. It is easy to notice that the features shown in the first three columns of Table II with the sign “+”, are adequate to the classical notion of plasma and prevail in most of the versions of the QGP definition. It is worth emphasizing that the Debay radius r_D should have been taken as the third feature which jointly with the condition 1 defines the linear sizes of the plasma.

Independence of the quark motion in QGP (feature 4 in Table II) cannot go together with the main property of the electron plasma - the collective interaction of its constituents. Thermalization (as feature 4 in Table II) is not obligatory a typical attribute of the plasma. The following question is still under discussion by theorists: Is the restoration of the chiral symmetry a typical feature of QGP?

And finally about the smallness of the quark mass (feature 6 in Table II). The mass of the charge carrier in the electron plasma is not its characteristic feature either. You see, the experimental data at RHIC [28] have shown that the masses of the fireball constituents are close to the constituent but not the current values of the quark masses. Thus, not all QGP features offered to identify it in experiments can go with the notion of plasma in the classical physics. The list of QGP features [1, 9] is lacking in its important collective properties related, in particular, with its oscillatory, i.e. quasiparticle degrees of freedom.

IV. CONCLUSION

So, the main properties of the hot and dense hadron matter observed at RHIC turned out to resemble more the usual electron plasma than the image of QGP which appeared from the simplest quark descriptions. The fireball medium did not behave like an ideal gas of particles. On the contrary, its constituents turned out to be strongly bound. They interact with hadrons by ~ 50 times stronger than the casual hadron matter and turned out for

them to be a rather opaque medium. Only this has motivated the title of this medium as “plasma” with strongly interacting quarks and gluons (sQGP) [9],[29]. In the meanwhile, to identify this state of the matter produced at RHIC as the state of the plasma, it is necessary to obtain positive answers to the questions which still remain unclear:

- is the medium of the produced fireball able to excite wave degrees of freedom in it?
- can the fireball medium screen the color charges?
- what is the nature of the collective character of constituent interactions in the fireball?

To answer the above, new experiments are needed to carry out. Of principal importance among them is the search for thermal photons emitted by the equilibrium and thermal QGP medium if this medium appears in the nuclei collisions at the RHIC energies. The knowledge of the photon spectrum is equal to the direct measurement of the temperature of the irradiating medium [30]. In this case by using the color analogue of the Saha formula for ordinary plasma obtained in the work [31], it is possible to estimate quantitatively the degree of deconfinement.

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TABLE I: Summary of comparative features of the electron plasma and fireball produced in the collisions at RHIC and SPS, CERN.

Properties - features of the electron plasma		Fireball properties – analogues of the electromagnetic plasma	Experimental confirmation	References
1	quasineutrality of the total electric charge	neutrality of the total color charge	is present	[14]
2	charge separation the plasma volume (dissociation of atoms)	deconfinement of the quarks of nucleon	is absent	-
3	collective character of the particle interactions	collective character of quark interactions in the fireball medium	is present	[15],[17]
4	Presence of the quasi-particle excitations in the system	presence of quasi-particle excitations in the fireball medium	there are experimental indications	[17],[19]-[21]
5	field screening of electric charges	screening of the color charge field	there are experimental indications	[25]-[27]

TABLE II: Summary of the QGP signatures according to its definitions in [[1]-[9]].

		1980	1983	1984/86	1984	1989	1996	1999	2004	2005
1	Deconfinement of quarks	+	+	+	+	+	+	+	+	+
2	Energy necessary for quark deconfinement	+	+	+	+	-	$+ (> T_c)$	+	+	-
3	Size of plasma bigger than nucleon size	-	-	+	+	+	-	+	-	+
4	Independence of quark motion	-	+	+	+	+	-	-	-	thermalization of constituents
5	Chiral symmetry restoration	-	+	-	-	-	-	+	+	-
6	Smallness of quark masses	-	+	-	-	-	+	-	-	-
	References	[1]	[2]	[3]	[4]	[5]	[6]	[7]	[8]	[9]

Note:

signs “+/-” mean that the indicated feature is or not necessary in the given definition of

plasma; T_c – is a temperature of phase transition from the nucleon matter to QGP.